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AN EVALUATION OF
SEEDLING INVENTORY
SAMPLING METHODS

USDA, Forest Service
Mt. Sopris Tree Nursery

Carbondale, Colorado

AUGUST 1976



Rocky Mountain Region

U.S. Department of Agriculture Forest Service

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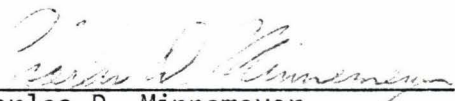
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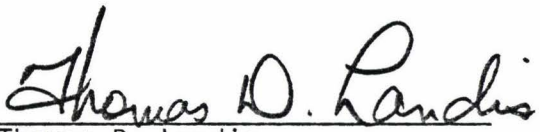
USDA, Forest Service
Mt. Sopris Tree Nursery

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AUGUST 1976

PREPARED BY:


Charles D. Minnemeyer
Statistician (Biologist)


Thomas D. Landis
Plant Pathologist

APPROVED BY:


G. L. DOWNING
Staff Director
Forest Insect and Disease Management


F. A. DORRELL
Deputy Regional Forester
State and Private Forestry

INTRODUCTION

An evaluation of seedling inventory sampling methods at the U. S. Forest Service Mt. Sopris Nursery near Carbondale, Colorado was conducted by Charles Minnemeyer and Tom Landis of Forest Insect and Disease Management on August 16 and 17, 1976. This evaluation was made at the request of Carroll McAninch, Acting Nurseryman. Sampling of the stock in the past has not been adequate and has resulted in poor estimates of the number of trees available for shipment. Inaccurate seedling inventories can seriously disrupt forest regeneration planning especially when planting contracts are involved.

This report discusses some of the problems associated with sampling at the nursery, outlines the old inventory method, and identifies some of the deficiencies of that method. Finally, some suggestions are made for improving the sampling system and some specific methods are recommended.

FACTORS WHICH COMPLICATE SAMPLING AT THE NURSERY

Seedling density in most beds at Mt. Sopris Tree Nursery is quite variable. Some beds are well stocked while others are poorly stocked. Intra-bed tree densities vary from adequate to very poor. Obtaining an accurate estimate of the actual number of seedlings present becomes more difficult as the variability increases.

Irregular seedling densities can be caused by several factors. Some of the variability is undoubtedly a result of differences in soil type within the nursery. Severe weed competition and losses to damping-off fungi are responsible for localized seedling mortality, which results in irregular seedbed densities. Seedling density can be related to seed source (seed viability); certain sources provide consistently good densities while others are more erratic. Inconsistency in planting practices, irrigation, and fertilization have probably caused some variation. All of these factors combined have contributed to highly variable sampling counts which result in a poor estimate of the number of seedling stock.

Until some of these nursery production problems are alleviated, an accurate seedling inventory will be difficult. The variability caused by some of these factors, such as weed problems, cannot be reduced by changing the sampling system. However, some steps can be taken to improve the inventory. As these steps are refined, and the nursery cultural practices improve the uniformity within the beds, a sampling system which will provide an acceptable level of accuracy can be achieved.

THE CURRENT SAMPLING METHOD

The current seedling inventory system consists of a stratified sampling design with each seed source considered a discrete population. Samples are taken by laying a metal frame, (1 x 4 ft) across the seedbed and counting all trees within the frame. Samples are collected at regular intervals along the standard 408 ft. bed so that 5 samples are taken in each bed. The points at which these samples are taken remains the same for each bed for each annual inventory. The number of trees in each count and the total lineal feet of bed for that seed source are recorded. The five counts for each bed are totaled and averaged. That average is rounded down by dropping any decimal fraction. This number is multiplied by 408 (feet in the bed) to give the total seedling count per seedbed. For seed sources less than a full bed in length, the number of counts for that source are averaged, the decimal fractions dropped, and that number multiplied by the length of seedbed occupied by that source. In sources extending over several beds, the total counts for each bed are added to give the estimated number of trees for that seed source. An example of the calculations used to obtain an estimate of the number of trees of a given seed source is given in Table 1.

TABLE 1. Example of current inventory calculations at Mt. Sopris

<u>3-0</u>	<u>ES</u>	<u>3-11</u>	<u>(SJ 10-73)</u>
<u>Bed 1</u>	<u>Bed 2</u>	<u>Bed 3</u>	<u>Bed 4 (partial)</u>
30	26	25	10
32	49	22	7
12	25	19	
20	26	22	(132')
31	28	14	
5 <u>125</u>	5 <u>154</u>	5 <u>102</u>	2 <u>17</u>
25.0	30.8	20.4	8.5
25	30	20	8
<u>408</u>	<u>408</u>	<u>408</u>	<u>132</u>
10200	12240	8160	1056
31,656			

EXPLANATION: The information on the top line identifies the age, species of tree, nursery location (block and unit), and seed source (forest and seed lot number), respectively. The columns below are the seedling counts. These are totaled, averaged, the decimal fraction dropped, and the resultant number multiplied by the number of feet in the bed. These figures are then added to give the final estimate which is the number on the bottom line.

The method of calculation shown in Table 1 can lead to poor estimates of the available inventory because of several factors. The most serious weakness of this method is that the final total is accepted as an exact figure for the number of seedlings of that source. No provisions are made during the calculations for the variability between the individual counts and the final estimate. The main purpose for taking several samples from a given population is to obtain a mean and an estimate of the variability between samples which is then used to set confidence limits on the reliability of the estimate.

Using the values given in Table 1 and not dropping the decimal fraction yields an estimate of 31,747 seedlings $\pm$ 5,692 with a 90% confidence interval. This means that the best estimate of the number of seedlings in this seed source is 31,747. However, it is very unlikely that this value is exactly correct, but we can now say with 90% confidence that the actual number of seedlings is 31,747 plus or minus 5,692. This gives a range of the estimated number of seedlings of 26,055 to 37,439. This information is far more useful to the nurseryman than the other estimate calculated by the old method.

A seedling inventory of shippable nursery stock was taken in the summer of 1976 using the current sampling system. Computation of 90% confidence limits for the inventory estimates revealed considerable variability (Table 2). Seed sources occupying a short length of seedbed had the most variation because of the inherently small number of samples taken. Much of this variability is a result of irregular seedling densities within the seedbeds. For example, seedling counts from one seedbed ranged from 0 to 196 trees per frame; another seedbed had seedling counts ranging from 2 to 256 trees. The total 1976 inventory was estimated at 1.8 million seedlings but we can only be 90% confident that the true value is between 1.3 and 2.4 million trees.

PROBLEMS WITH THE CURRENT SAMPLING METHODS

Many samples yielded counts of zero which indicates that these areas are non-stocked. Unstocked portions of the bed should not be sampled; the total length of seedbed with no trees should be subtracted from the total bed length.

The current sampling system is not randomly designed. Each count is made at the same spot in the bed because the sampling points are determined by positions on the irrigation pipes. Because of this fixed sampling pattern any periodicity in distribution of water or fertilizer or changes in soil characteristics can influence the sample.

One of the biggest weaknesses of the old sampling method is the uniform intensity at which all beds are sampled. The sampling scheme should be based on the biological population which is the seed source, rather than on the geographical limits of the seedbed. One seed source was only 72 feet long, and only 1 count was made within that seed source. There is a need for a greater sampling intensity as the total lineal feet of bed decreases. Without increased sampling intensity on the smaller beds, there will not be enough counts to get a reliable measure of variability to make the estimate and set confidence limits.

SUGGESTIONS FOR IMPROVING THE INVENTORY SAMPLING PROCEDURE

The following are suggestions for improving the estimate of the number of tree seedlings at Mt. Sopris Tree Nursery. Several have already been utilized on a limited basis during the fall inventory of 1976. These suggestions are just that and should be tested before they are incorporated into the inventory program on a permanent basis. Those which are not practical should be discarded and those that are useful but need improvement should be modified.

It must be emphasized that little improvement in the accuracy of the seedling inventory should be expected until some of the production problems at Mt. Sopris can be alleviated. Only when the within-bed variation is reduced, can accurate estimates be obtained.

1. The size of the sampling frame could be reduced by half to minimize the intensity of sampling at one point. A sample frame 6 inches wide, instead of the current 12 inches, would decrease the amount of time spent per frame and allow more samples to be taken. All of the calculations shown in the appendices were developed with the assumption that a frame 6 inches wide would be used in the sampling. These calculations would not be applicable for a 1 foot frame.
2. All sampling should be done by the same personnel to minimize technician error. The sampling crew should consist of professionals or responsible seasonals to insure that sampling techniques are consistent.
3. Individual seed sources should be the sampling populations. The number of plots per source will depend on the total length of seedbed in that source. Before any plots are taken, the total length of adequately stocked seedbed should be determined. For seed lots of less than 1,000 feet 20 plots should be taken initially, and for larger sources, one additional plot should be added for each additional 50 feet of seedbed. The interval between sampling points can be determined by dividing the total seedbed length by the number of plots.
4. The point at which the first sample is taken should be randomly selected. After the number of samples are determined for a given seed source, the first sample should be taken at a point randomly selected between the start of the seedbed and

within the sampling interval. For example if the interval between sampling points is 25 feet, then the first sample will be taken at a randomly selected point between 0 and 25 feet from the start of the seedbed and successive samples will be taken at 25 foot intervals thereafter.

5. Any portion of the seedbed which is bare or essentially non-stocked should be eliminated from the sampling area and the lineal feet of such area should be deducted from the total lineal feet of bed for that seed source. The nurseryman should set minimum stocking levels that can be used to identify areas of seedbed that contain an unacceptable number of seedlings.
6. A cull factor should be calculated during the field sampling to obtain an estimate of the number of unmerchantable seedlings in each seed source. In each sampling frame one row should be randomly selected and all seedlings in that row graded for merchantability. In beds where there are six rows, the field crew could easily throw a die to select the cull row. A percent cull can therefore be obtained for each frame; combining all of these for a given seed source should provide a reasonable estimate of the percent cull.
7. Regardless of the number of samples collected, an estimate of variation should be calculated for each seed source. Using the formulas in Appendix I, the sample mean and standard error should be determined. These statistics can then be used to obtain confidence intervals that should be included in the nursery inventory to give an estimate of the reliability of the seed source population means.

After all samples have been collected, the adequacy of this number of samples should be determined. Formulas are presented in Appendix II that will indicate whether additional samples are needed for a particular seed source. If more samples are recommended, it is up to the nurseryman to decide whether additional sampling can be economically justified.

8. Certain portions of the nursery have chronic tree production problems which results in irregular seedbed densities. These areas should be identified before initiation of seedling inventories because special sampling methods may be needed to obtain an adequate sample.

TABLE 2 1976 Mt. SOPRIS NURSERY INVENTORY WITH 90% CONFIDENCE LEVEL

BLOCK	SPECIES	FOREST	SOURCE	$\bar{x}$	n	$\overline{sx}$	FEET OF BED	ESTIMATE ($\bar{x}$) (FEET OF BED)	90% C.I.	
									LOW	HIGH
1	DF	Santa Fe	28-63	9.571	28	1.972	2,316	22,166	14,683	29,944
1	DF	Pike	2-65	8.182	11	1.925	852	6,971	3,999	9,943
1	DF	Carson	12-63	20.900	10	5.809	816	17,054	8,365	25,743
1	DF	Carson	12-63	19.667	30	4.161	2,292	45,077	28,874	61,280
1	BCP	Carson	22-73	16.100	20	2.049	<u>1,452</u>	<u>23,377</u>	<u>18,233</u>	<u>28,521</u>
							7,728	114,645	73,859	155,431
3	ES	S.J.	18-72	28.200	10	3.309	816	23,011	18,062	27,960
3	ES	S.J.	18-72	11.820	50	.835	4,080	48,226	42,189	54,263
3	ES	S.J.	18-72	16.600	10	2.161	816	13,546	10,314	16,778
3	ES	S.J.	12-72	24.725	40	2.384	3,264	80,702	67,590	93,814
3	ES	S.J.	12-72	18.000	15	4.274	1,224	22,032	12,820	31,244
3	ES	S.J.	16-72	8.600	35	1.258	2,856	24,562	18,486	30,638
3	ES	S.J.	16-72	12.800	5	4.716	408	5,222	1,120	9,324
3	ES	S.J.	2-72	13.067	15	1.722	1,224	15,994	12,282	19,706
3	ES	S.J.	10-73	23.412	17	2.404	1,356	31,747	26,055	37,439
3	ES	S.J.	10-73	48.800	10	5.234	816	39,821	31,992	47,650
3	ES	Gm-Unc	7-68	6.333	12	.924	936	5,928	4,375	7,481
3	ES	Gunn	14-72	2.278	18	.351	1,512	3,444	2,524	4,364
3	ES	Carson	9-73	9.540	50	.973	4,080	38,923	32,266	45,580
3	ES	Santa Fe	29-63	10.545	33	.971	2,652	27,965	23,603	32,327
3	ES	W.R.	5-73	5.063	16	1.066	1,356	6,865	4,331	9,399
3	ES	W.R.	1-72	17.000	1	---	72	1,224	---	---
3	ES	W.R.	1-72	11.353	17	1.581	1,368	15,531	11,755	19,307
3	ES	R.G.	8-68	10.935	31	1.532	2,556	27,950	21,305	34,595
3	ES	R.G.	8-68	12.455	33	1.507	2,724	33,927	26,973	40,881
3	ES	Routt	32-65	8.500	2	6.500	<u>156</u>	<u>1,326</u>	<u>---</u>	<u>7,728</u>
							34,272	467,856	369,266	571,466
8	PP	Gm-Unc	66-5	15.278	18	2.449	1,404	21,453	15,470	27,436
8	PP	B.H.	20-72	35.696	23	7.102	<u>1,806</u>	<u>66,395</u>	<u>43,714</u>	<u>89,076</u>
							3,210	87,848	59,184	116,512
10	ES	S.J.	13-73	35.500	10	6.145	816	28,968	19,777	38,159
10	ES	S.J.	13-73	21.818	33	1.812	2,640	57,600	49,492	65,708
10	ES	S.J.	11-73	17.417	12	2.927	1,032	17,974	12,549	23,399
10	ES	Gm-Unc	7-68	26.800	5	8.434	408	10,934	3,598	18,270
10	ES	Gm-Unc	7-68	16.588	17	2.714	1,368	22,692	16,210	29,174
10	WF	R-3	59-62	9.176	17	1.754	<u>1,368</u>	<u>11,184</u>	<u>6,995</u>	<u>15,373</u>
							7,632	149,352	113,411	185,221
11	LPP	Arap.	5-67	29.571	7	14.619	600	17,743	700	34,786
11	LPP	Arap.	5-67	37.500	10	16.214	816	30,600	6,348	54,852
11	LPP	Arap.	12-64	41.300	20	8.339	1,524	62,941	40,968	84,914
11	LPP	Bigh.	14-74	6.625	7	2.941	684	4,532	624	8,440
11	LPP	Bigh.	16-74	50.346	26	7.443	2,052	103,310	77,224	129,396
11	LPP	Bigh.	15-75	14.571	17	3.670	528	7,693	4,310	11,076
11	LPP	Shos.	23-73	28.281	32	2.775	2,604	73,644	61,391	85,907
11	LPP	Shos.	23-73	38.231	13	6.269	996	38,078	26,951	49,205
11	LPP	Gunn.	31-74	32.118	17	5.562	1,404	45,094	31,459	58,729
11	LPP	Routt	70-4	16.350	40	3.426	3,084	81,263	63,470	99,056
11	LPP	Routt	70-4	8.100	50	1.441	4,080	33,048	23,183	42,913
11	LPP	Routt	70-4	3.316	38	.607	3,024	10,023	6,930	13,126
11	PP	Santa Fe		80.391	23	12.511	1,938	155,798	114,167	197,429
11	PP	Santa Fe		55.000	4	17.325	228	12,540	3,245	21,835
11	PP	Wyo-St.		59.25	4	19.813	276	16,353	3,486	29,220
11	PP	Pike	60-64	109.091	11	18.528	900	98,182	68,233	128,131
11	PP	S. Isabel	19-72	40.333	6	7.301	504	20,328	12,913	27,743
11	ES	S.J.	13	9.100	10	2.079	792	7,207	4,189	10,225
11	ES	Carson		180.500	2	35.500	204	36,822		82,548
11	DF	Carson		151.273	11	24.723	924	139,776	98,374	181,178
11	DF	W.R.	1-65	12.500	6	3.354	634	7,925	3,640	12,210
11	WF	Carson		.700	10	.300	<u>852</u>	<u>596</u>	<u>273</u>	<u>919</u>
							18,048	1,003,501	652,062	1,363,838
							81,450	1,823,202	1,262,988	2,397,566

APPENDIX I ESTIMATING NUMBER OF SEEDLINGS IN A SEED SOURCE
AND CALCULATION OF CONFIDENCE INTERVALS

<u>SAMPLE NUMBER</u>	<u>SEEDLING COUNT</u>	<u>SEEDLING COUNT SQUARED</u>	<u>SAMPLE NUMBER</u>	<u>SEEDLING COUNT</u>	<u>SEEDLING COUNT SQUARED</u>
1			21		
2			22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		
COLUMN TOTAL			COLUMN TOTAL		
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APPENDIX I (continued)

N = Total number of samples in seed source

$\sum x$ = Total viable seedlings counted in seed source

Mean sample count: $\bar{x} = \frac{\sum x}{N} =$

Mean estimate of seedlings in seed source = $\frac{\sum x}{N} \times 2 \times \text{ft. of bed} =$

Variability

Sample variance: $s^2 = \frac{\sum x^2 - \frac{(\sum x)^2}{N}}{N - 1}$

Sample Standard Deviation: $s = \sqrt{s^2} = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{N}}{N - 1}} =$

Sample Standard Error: $\bar{Sx} = \frac{s}{\sqrt{N}} =$

Confidence Intervals (C.I.):

Use 1.729 for 90% C.I. and 20 samples

Use 2.145 for 95% C.I. and 20 samples

Check statistical tables of "Students t-distribution" for appropriate value to use when more than 20 samples are taken.

To calculate 90% C.I. for 20 samples:

$$\left[\bar{x} \pm 1.729 (\bar{Sx}) \right] \times 2 \times \text{ft. of bed} = (\text{mean estimate})$$

$$\left[\bar{x} + 1.729 (\bar{Sx}) \right] \times 2 \times \text{ft. of bed} = (\text{high estimate})$$

$$\left[\bar{x} - 1.729 (\bar{Sx}) \right] \times 2 \times \text{ft. of bed} = (\text{low estimate})$$

APPENDIX I (continued)

N = Total number of samples in seed source

$\sum x$ = Total viable seedlings counted in seed source

Mean sample count: $\bar{x} = \frac{\sum x}{N} =$

Mean estimate of seedlings in seed source = $\frac{\sum x}{N} \times 2 \times \text{ft. of bed} =$

Variability

Sample variance: $s^2 = \frac{\sum x^2 - \frac{(\sum x)^2}{N}}{N - 1}$

Sample Standard Deviation: $s = \sqrt{s^2} = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{N}}{N - 1}} =$

Sample Standard Error: $\bar{Sx} = \frac{s}{N} =$

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$$\left[\bar{x} + 1.729 (\bar{Sx}) \right] \times 2 \times \text{ft. of bed} = (\text{high estimate})$$

$$\left[\bar{x} - 1.729 (\bar{Sx}) \right] \times 2 \times \text{ft. of bed} = (\text{low estimate})$$

APPENDIX II HOW TO CALCULATE IF MORE SAMPLES NEED TO BE TAKEN

Decide: (1) What probability is desired, 90%, 95% etc.

(2) Within how many units (seedlings) of the true mean the estimate needs to be at the given probability.

Convert the units (seedlings) back to mean sample count ($\bar{x}$)

Example: If the estimate desired is to be within 2000 seedlings and the bed is 500 ft. long then mean sample count ($\bar{x}$)

$$\text{change will be } \frac{2000}{2 \times 500} = 2$$

When expanded, using the formula for mean estimate of seed source, the mean sample count change of 2 produces an overall estimate change of ($\bar{x}$) $\times$ (2) $\times$ (ft. of bed) =
 $2 \times 2 \times 500 = 2000$

Let the unit of change (seedlings per sample) = L

The formula for determining sample size is $N = \frac{p^2 (s^2)}{L^2}$

s^2 is the sample variance (computed previously). p^2 is the square of the tabulated value of the normal curve (expressed in standard deviation units) at the desired probability. For 90% C.I., $p^2 = 2.7$; for 95% C.I., $p^2 = 3.8$

APPENDIX II (continued)

Example: If seedbed is 1000 ft. and prior 20 samples give $\bar{x} = 15$,
 $s^2 = 10$, $S\bar{x} = .707$ Mean estimate for seed source
 is $(\bar{x}) \times (2) \times (\text{feet of bed}) = 15 \times 10 \times 1000 =$
 30,000 seedlings.

$$90\% \text{ C.I.} = [\bar{x} \pm 1.729 (S\bar{x})] \times 2 \times \text{feet of bed}$$

$$90\% \text{ C.I.} = [15 \pm 1.729 (.707)] \times 2 \times 1000 = 30,000 \pm 2445$$

If it is desired to have 90% C.I. within 1000 seedlings of mean
 estimate of seed source then mean sample count change will be

$$\bar{x} \text{ change} = \frac{1000}{2 \times 1000} = .5 = L$$

$$\text{To compute } N \text{ use } N = \frac{p^2 (s^2)}{L^2}$$

$$N = \frac{p^2 (s^2)}{L^2} = \frac{2.7 (10)}{.5} = \frac{27}{.25} = 108$$

Therefore: $108 - 20 = 88$ more samples are needed